AD View of Run 2e + NOvA

("e" for "extension")

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AD Task Force

- Formed early August to address several issues quickly for PAC meeting

- What happens to 2012 accelerator shutdown if only pursuing the Main Injector upgrades? (i.e., Recycler remains pbar storage ring for Collider)
- Can we really increase the Booster batch intensity by ~20%?
- Can we really sustain collider luminosity (integrated) with 30% lower proton flux on pbar production target?
- How much time would it take to change working tune point of Tevatron?

References

- "Run 3" document
  - http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=3617
- Proton Source Task Force report
  - http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=3660

Current Plan to Reach 700 kW for NOvA

- Decreasing Main Injector ramp time
  - Upgrade quadrupole bus power supply + 2 additional RF stations
- No sharing protons with pbar production
  - 2 more proton batches/cycle available (9 → 11 batches)
- Proton stacking in Recycler
  - Recycler can accommodate 1 more batch than MI slip-stacking (12 total)
  - Negligible filling time from Recycler allows faster MI cycle time
- Increasing Booster flux to get 14×10^{16}/hr (NOvA alone)
  - Current total flux = 11×10^{16}/hr @ ≈7 Hz (NuMI + pbar + MiniBoone)
  - NuMI: 4.3×10^{12}/batch @ 5 Hz → NOvA: 4.3×10^{12}/batch @ 9 Hz
  - New Booster shielding assessment in progress

Simultaneous Collider & NOvA Operation

- Retain Recycler solely for Collider – need high pbar brightness
  - 2012 accelerator shutdown could be shortened (less work in MI tunnel)
- Based on current total Booster flux = 11×10^{16}/hr for (NOvA + pbar)
- Implement improvements for faster MI ramp time
- Interleave pbar production cycles (9 NOvA+2 pbar batches every other MI cycle)
  - Pbar stochastic cooling less efficient for shorter ramp cycles
  - NOvA can take all 11 proton batches on non-pbar cycles
  - Already do this occasionally when stuck with large pbar Accumulator stack
  - Pbar stacking rate will be lower; discuss impact on luminosity later
- Could achieve 500 kW for NOvA in this scenario
  - All modifications within already planned costs for NOvA upgrades
  - Proton source upgrades would contribute also

Proton Flux Allocation

	NuMI	NOvA	Run 2e	units
Booster Cycle Rate	5.00	9.00	5.89	Hz
NuMI/NOvA Booster Batches	9	12	10	
NuMI/NOvA Booster Batch Intensity	4.30	4.30	5.10	$\times10^{12}$
Antiproton Booster Batches	2	N/A	1	
Antiproton Booster Batch Intensity	4.60	N/A	5.50	$\times10^{12}$
Main Injector Fill Time	0.67	0.00	0.67	sec
+ Main Injector Ramp Time	1.53	1.33	1.20	sec
= Main Injector Cycle Time	2.20	1.33	1.87	sec
Main Injector Efficiency	95	95	95	%
Main Injector 120 GeV Intensity	45.51	49.02	53.68	$\times10^{12}$
Main Injector Beam Power Loss	1.39	2.48	1.94	kW
Antiprotons Used in Recycler	Yes	N/A	Yes	
Antiproton Cycles Interleaved	No	N/A	Yes	
Antiproton Cycle Time	2.20	N/A	3.73	sec
Booster Flux	7.84	13.93	10.90	$\times10^{16}$/hr
Antiproton 120 GeV Proton Flux	1.43	0	1.01	$\times10^{16}$/hr
NuMI/NOvA Beam Power	**321**	**706**	**498**	**kW**

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Shutdowns

- What if only pursuing Main Injector upgrades in 2012? *(faster cycle time)*
  - Install additional power supply for quadrupole bus
  - Install 2 additional 53 MHz RF cavities
  - → Duration for accelerator work = 8-12 weeks *(from NOvA plan)*

- Minor issues:
  - Tevatron keeps solid-state RF amps destined for MI ($160K)
  - Need to accommodate keeping the 106 MHz cavity for coalescing
    - Plan was to remove that and one used only for studies for new 53 MHz cavities

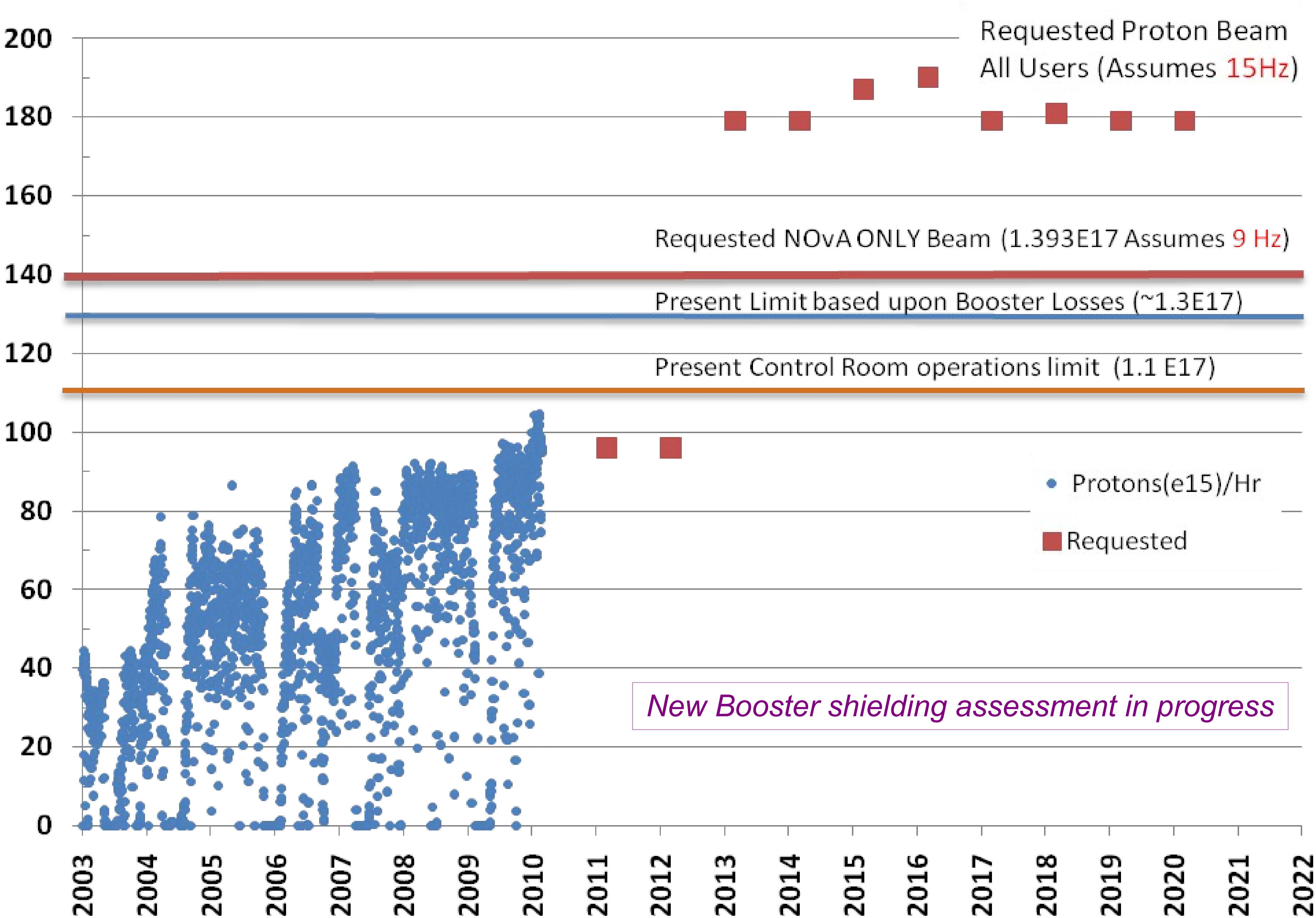
- NOvA: new target & horn relocation + near detector excavation
  - Duration = 7-8 months

- After Collider Run, AD would need another 7-8 month shutdown
  - Reconfigure Recycler for proton stacking

Booster Flux

- Trade-offs between intensity / losses / beam quality / rep rate / reliability
- Can the Booster deliver 5.1/5.5 $\times 10^{12}$ per batch (NOvA/pbar)?
  - ~4.8$\times 10^{12}$ for MiniBoone; > 5$\times 10^{12}$ for TeV protons
  - RF-limited in mid 5's – greater sensitivity to losing even 1 cavity
  - Booster can deliver > 5 $\times 10^{12}$ per batch with greater susceptibility to instabilities and RF failures
- At acceptable beam power loss to minimize tunnel activation?
  - Both Run 2e and 700 kW NOvA (alone) push 525 W limit (currently ~420 W)
  - Beneficial to improve efficiency through studies and upgrades
- And with acceptable beam quality for Main Injector slip-stacking?
  - Not demonstrated at higher intensity - needs studies and effort
- Can Booster operate at desired rep rate as-is? 5.89 Hz = yes, 9 Hz = no

Booster Flux History and Requests [E15/hr]



Booster Upgrades

- Complete implementation of new correctors (ongoing)
  - Improve efficiency, beam quality
- Solid-state RF drivers required to achieve 9 Hz operation
  - Currently limited by funding and manpower – estimate completion in 2014 *(from Proton Source Task Force report)*
  - Until then, rep-rate max 7.5 Hz $\rightarrow$ NOvA $\leq$ 580 kW if given all Booster flux
- Install 20th RF cavity during 2012 shutdown
  - Per recommendation of Proton Source Task Force
  - Raise RF-limited beam intensity, help reliability
- RFQ to replace the ion sources + Cockroft-Waltons
  - Likely ready for 2012 shutdown, but beamline elements not yet funded
  - Help reliability, possibly beam quality
- Upgrades directly address rep-rate and reliability, not batch intensity

Main Injector Concerns

- Slip-stacking efficiency depends strongly on beam quality from Booster
  - Longitudinal emittance and momentum spread are key
  - Want ≥ 95% efficiency to limit activation of MI components & tunnel
  - Can achieve 95% / 90% with current conditions at 4.3 / 4.6 $\times 10^{12}$ per batch
  - Not yet at higher proposed intensities - needs coordinated studies and effort

- Faster MI cycle time
  - Default NOvA ramp + injection from Booster → 1.333 + 0.667 = **2.000 sec**
  - Eliminating 1 Booster 15 Hz tick is straightforward → **1.933 sec**
    - Magnet power supplies can support 1.2 sec ramp *(max ramp rate = 240 GeV/s)*
  - Saving 1 more Booster tick possible, needs effort → **1.867 sec**
    - Turning on feedback loops at injection, performing bunch rotation during ramp
  - Each saved tick adds ~15 kW to NOvA for the given batch intensity range

- Cooling capacity at limit for 1.933 sec cycle – need more for shorter cycles
  - Create additional MI ponds and/or use Tevatron ponds

Impact on Antiproton Stacking

- Interleaving needed for MI cycle times < 2.0 sec
  - Pbar throughput is trade-off between proton flux and cooling time
  - Better to have higher proton intensity and longer cooling time
  - Some components not designed for faster times (Accumulator RF)

- Competing effects for higher protons on target (POT)
  - More protons → more pbars created at target
  - More pbars → lower cooling rate for constant cycle time

- Production efficiency increases for longer cycle times
  - Based on dedicated studies and operations (large Accumulator stacks)

- Minor concern about higher beam intensity/pulse on target
  - Recent typical = 8×10^{12} ; have run ~9×10^{12} POT in 2007
  - Newer target designs proving more reliable, but fallback is larger spot size

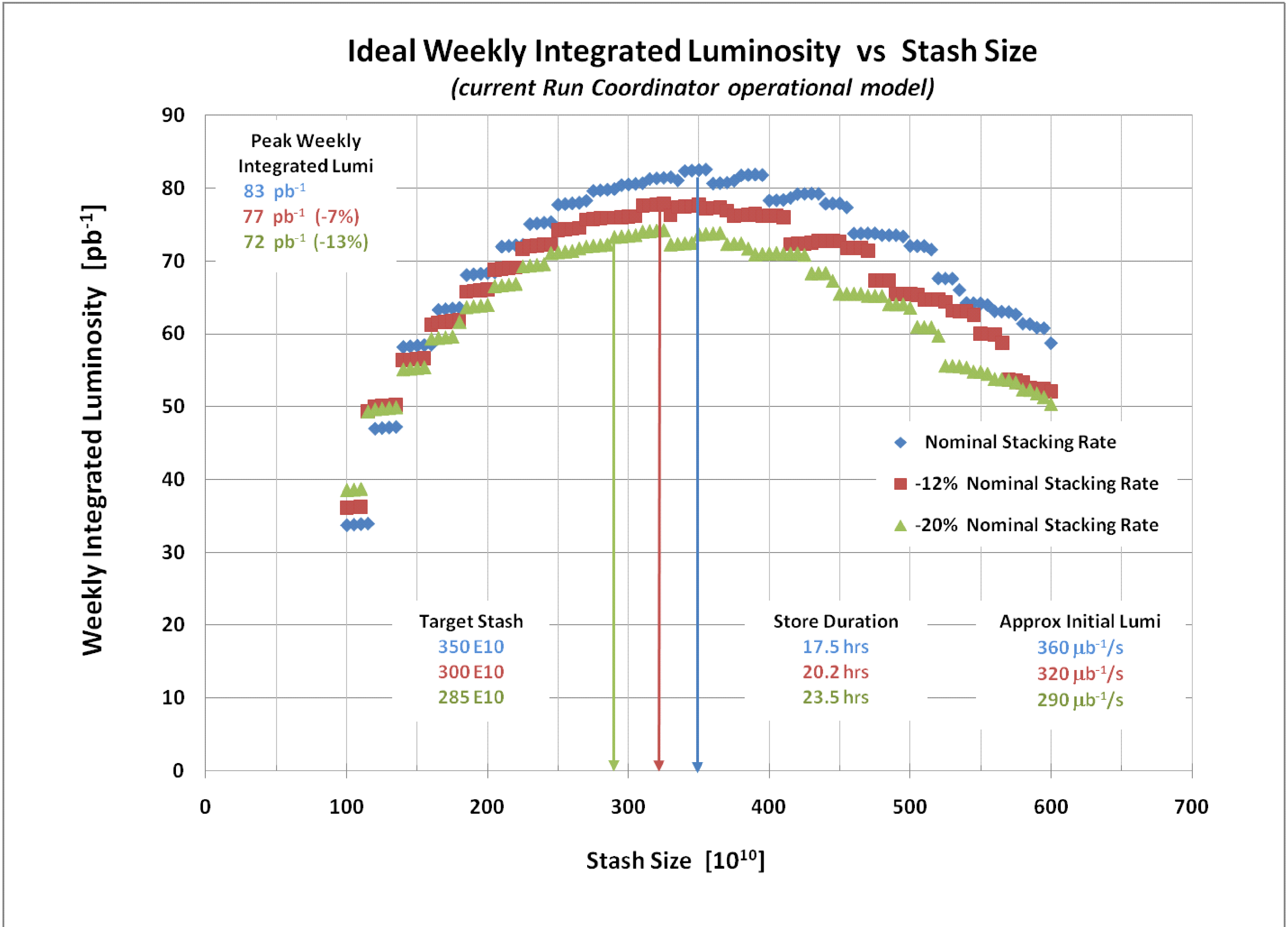
Antiproton Production Summary

Quantity	**Relative Change to Current Operations** Optimistic = 1.867 sec cycle time @ 5.5×10^{12}/batch	**Relative Change to Current Operations** Conservative = 1.933 sec cycle time @ 4.6×10^{12}/batch
Cycle Rate (with interleaving)	60%	57%
Protons on Target	120%	100%
Production Efficiency (Higher POT)	85% - 87.5%	100%
Production Efficiency (Longer Cycle Time)	140% - 150%	140% - 150%
Total Stacking Rate Change	**86% - 94%**	**80% - 86%**

Estimate 12% / 18% (high / low intensity) reduction in antiproton stacking rate

Impact on Tevatron Integrated Luminosity

- Current plan: 52.5 pb^{-1} / week for 44 weeks / year = 2.3 fb^{-1} / year
- Lower pbar stacking rate reduces integrated luminosity
- Use “battle-tested” operational model used by Run Coordinators
  - 12% stacking rate reduction → 7% reduction in weekly delivered lumi
  - 20% stacking rate reduction → 13% reduction in weekly delivered lumi
  - Store durations lengthen, target stash size & peak luminosity decrease
- Not a terrible impact – no prerequisite to implement changes
  - 2 fb^{-1} / year still possible with 20% lower stacking rate
- Make effort to recover lost luminosity (and do even better?)
  - Investigate higher proton intensities for current configuration
  - Move to new tune working point to allow higher proton intensity



Ideal Weekly Integrated Luminosity vs Stash Size
(current Run Coordinator operational model)
Peak Weekly Integrated Lumi
83 pb-1
77 pb-1 (-7%)
72 pb-1 (-13%)
Nominal Stacking Rate
-12% Nominal Stacking Rate
-20% Nominal Stacking Rate
Target Stash
350 E10
300 E10
285 E10
Store Duration
17.5 hrs
20.2 hrs
23.5 hrs
Approx Initial Lumi
360 μb-1/s
320 μb-1/s
290 μb-1/s
Weekly Integrated Luminosity [pb-1]
Stash Size [10^10]
0
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700

Tevatron ½ Integer Working Point

- To allow 30% more protons to make up for smaller stacking rate
- Simulations indicate improved luminosity lifetime, too
- Significant effort to implement, hard to be precise with time needs
  - Must change all aspects of operation: injection, ramp, squeeze, collisions
- Need dedicated studies for testing, measuring lattices, etc.
  - Continue to provide luminosity in current scheme in between studies
- When implementing, start with low intensities, gradually ramp up while evaluating performance, making corrections
  - Not unlike an extended start-up after a maintenance shutdown
- 1 month for dedicated studies, several more weeks for implementation?

Operational Costs

- Cost estimate to operate the Collider in FY12 = $40M
  - M&S, overhead, salaries, electricity
  - Tevatron, Antiproton Source, Recycler, support from APC, TD
  - Includes escalations for helium delivery and electricity

Other Considerations

- Feeding the 8 GeV program takes Booster cycles
  - Rep-rate max = 7.5 Hz until solid-state driver upgrade complete
  - Run 2e proposal is 5.9 Hz for Collider + NOvA, still 1.5 Hz left over
  - May need to trade-off batch intensity for rep-rate to stay below loss limits

- SeaQuest will use 120 GeV protons extracted from Main Injector
  - Slow-spill ~10^{13} protons over 5 sec flat-top, 24×7 operation
  - Can not neglect impact on NOvA / pbar beam delivery
  - 1 cycle / minute = >10% of available MI time for other 120 GeV cycles
  - Expect guidance from Program Planning

Conclusions

- Shutdowns
  - AD needs 8-12 weeks in 2012 for MI upgrades for faster cycle time
  - NOvA needs 7-8 months in 2012 for new target, horn moves, excavation
  - AD needs 7-8 months after Collider for proton stacking in Recycler

- Booster Flux
  - Current available RF voltage limits batch intensity to ~5.5×10^{12}
  - Rep-rate limited to 7.5 Hz until solid-state upgrade complete for 9 Hz

- Main Injector
  - Total cycle time = 1.933 sec (incl. injection from Booster) is straightforward
  - Minimum cycle time = 1.867 sec possible, requires more thought & studies

- Proposed Run 2e intensities may be possible, but will require significant coordinated studies between Booster and Main Injector to maintain acceptable beam power loss levels and 95% slip-stacking efficiency

Conclusions

- Antiproton Production
  - Impact of cycle time and higher beam intensity is understood
  - Stacking rate reductions 12-18% depending on conditions

- Tevatron Integrated Luminosity
  - Smaller stacking rate → 7-13% less integrated lumi; 2 fb^{-1} / year still feasible
  - Could recover lost lumi by moving to ½ integer working point
  - 1 month of semi-dedicated studies, then several weeks to implement into operations, gradually ramp up intensities, evaluate, make correction

- SeaQuest
  - Will share MI cycles with rest of 120 GeV program; don't neglect impact

- 8 GeV program needs Booster cycles, too
  - Impact on rep-rate, batch intensity to maintain Booster loss levels

Numbers for Comparison

Scenario		NOvA power [kw]	Tevatron delivered lumi / year [fb^{-1}]
Do nothing	4.3×10^{12} / Booster batch @ 2.2 sec MI cycle	320	2.3
Conservative	4.3×10^{12} / Booster batch @ 1.933 sec MI cycle	405	2.1
Optimistic	5.1×10^{12} / Booster batch @ 1.867 sec MI cycle	498	2.0
NOvA-only at Booster rate limit prior to solid state upgrade	4.3×10^{12} / batch @ 7.5 Hz @ 1.333 sec MI cycle	583	0

- No plan implied - difficult to guess at potential ramp-up in batch intensities
- Tevatron integrated luminosity based on current operating scenario
  - Design ("red line" goal): 52.5 pb^{-1} / week for 44 weeks / year
- Impacts of running 8 GeV program and SeaQuest neglected in this table